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U.S. Army Research, Development & Engineering Command

Power Considerations for Micro-Autonomous Systems

ARL

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Outline

- Army Needs & Niche
- Energy & Power Requirements
- Power Source Options
  - Bring energy with you
  - Get more on site
- Suggestions

Enduring Army Problems

- It is burdensome to carry & sustain everything
- Soldiers need to be more survivable
- There is never enough power
- We must operate in extreme environments
- 24/7 situational awareness of actions & intent is key to success

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Micro-Autonomous Systems & Technology (MAST) CTA

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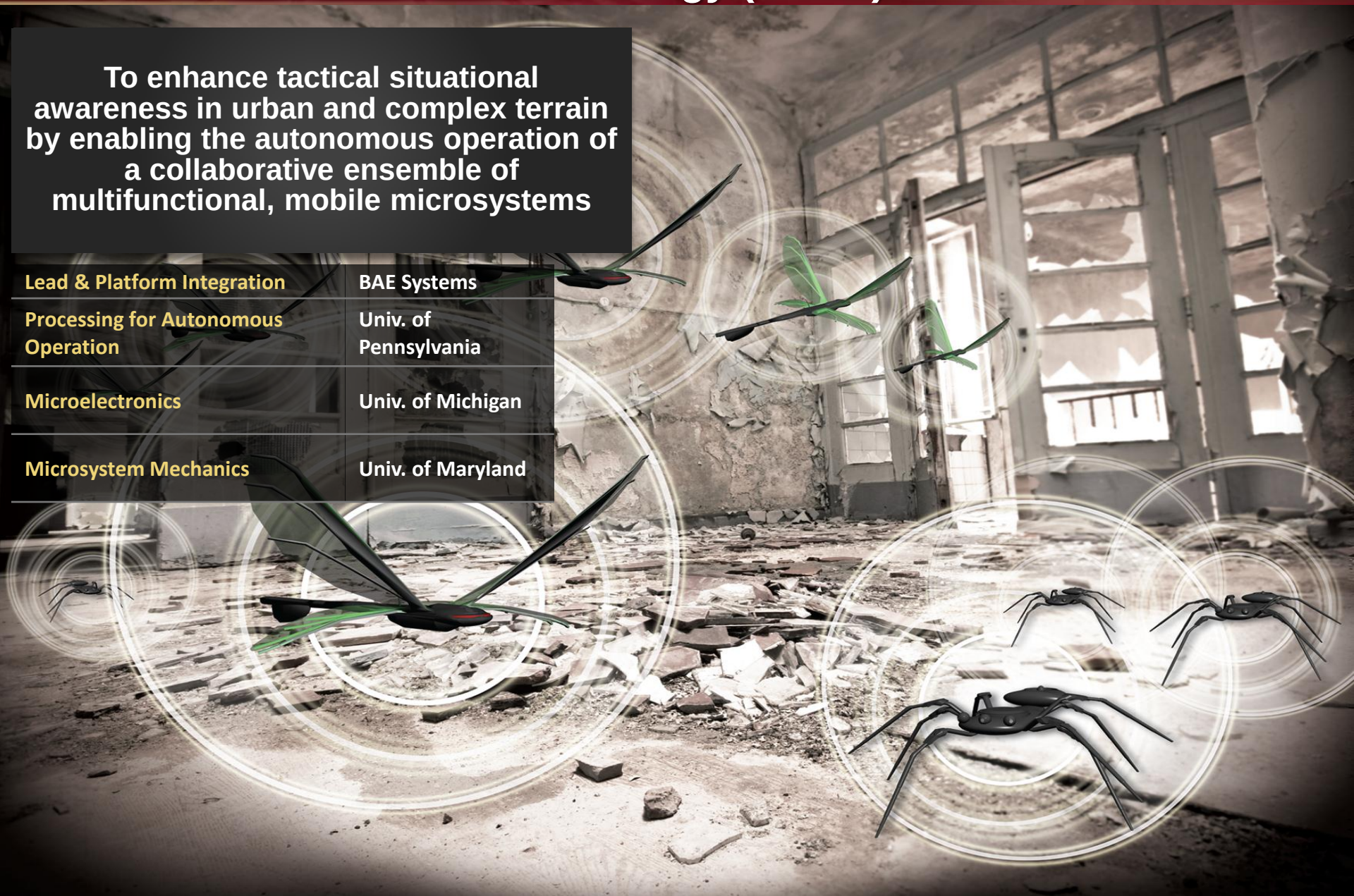
To enhance tactical situational awareness in urban and complex terrain by enabling the autonomous operation of a collaborative ensemble of multifunctional, mobile microsystems

Lead & Platform Integration	BAE Systems
Processing for Autonomous Operation	Univ. of Pennsylvania
Microelectronics	Univ. of Michigan
Microsystem Mechanics	Univ. of Maryland



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Autonomous Robot Landscape

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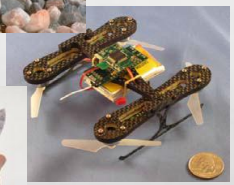
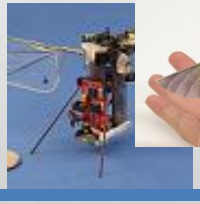
Biology

MAST Goal





1g

1kg

1000kg

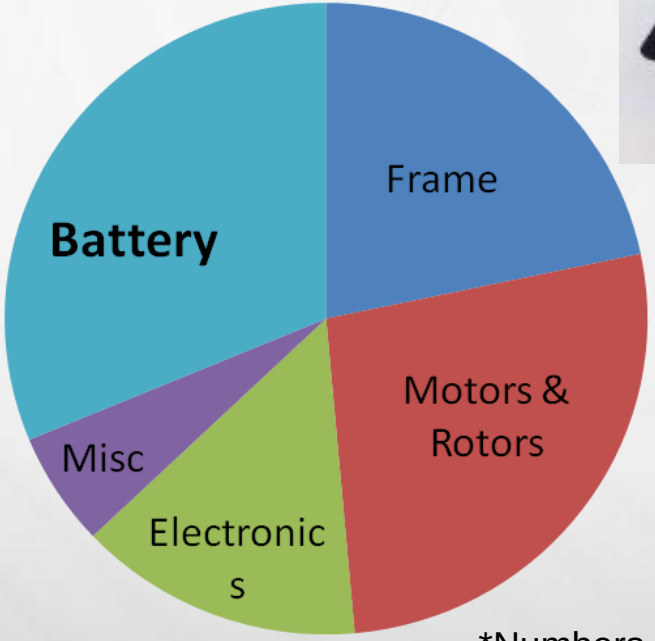
Size / Maturity

Autonomy

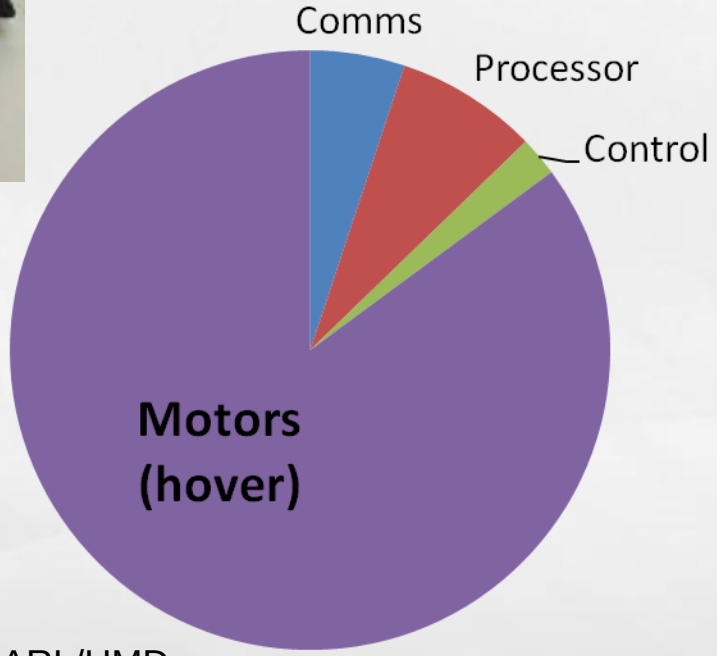
Energy & Power Needs

Representative Platform: DFS/UMD MicroQuad

Weight Breakdown (Total = 77.4g)



Power Breakdown (Total = ~12W)



*Numbers courtesy of Dr. Joe Conroy, ARL/UMD

Power for mobility dominates over sensors & Comms; especially for aerial platforms (~10:1)

Non-Ragone Plot

1

Specific Power of Source (W/g)

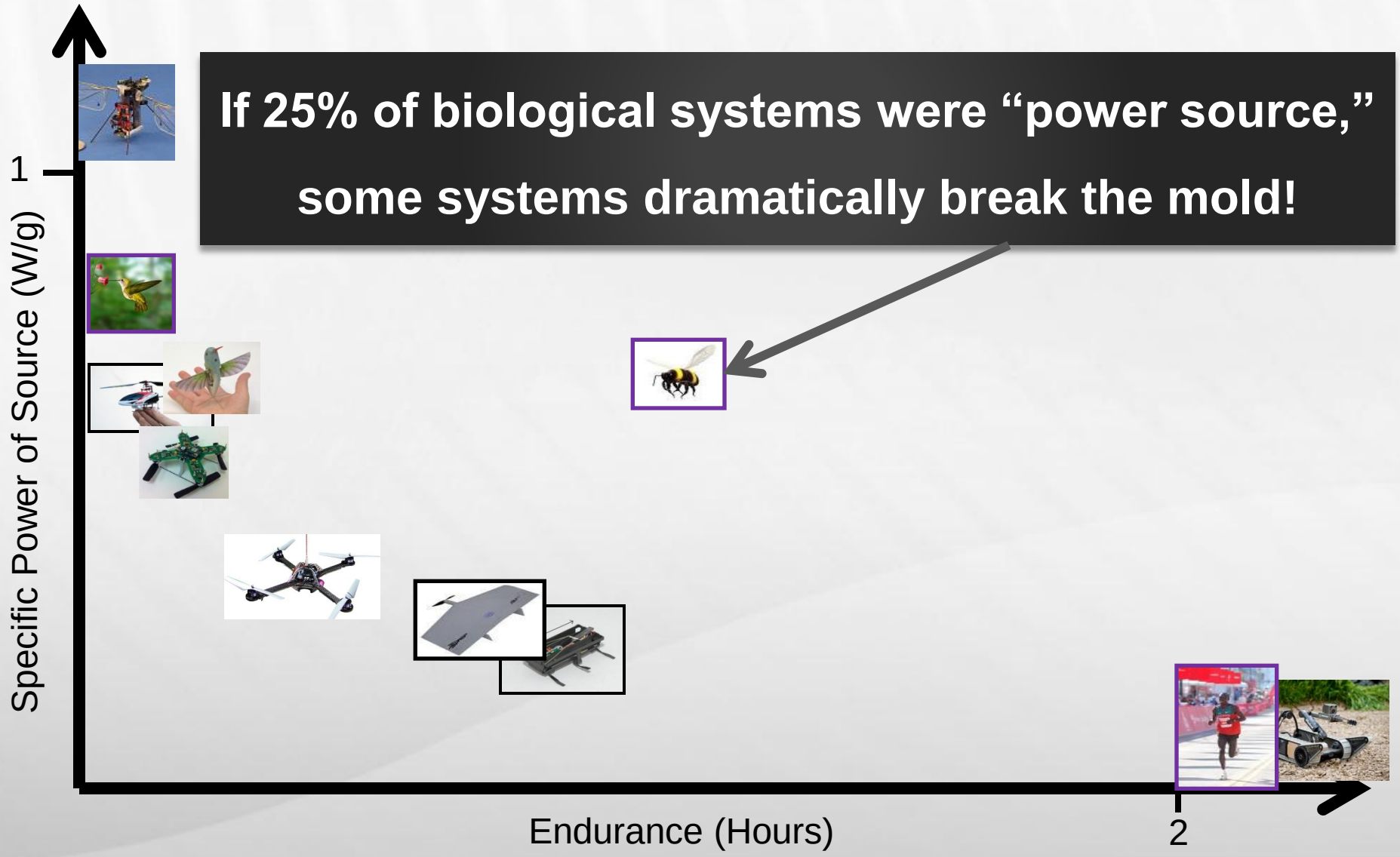
Endurance (Hours)

2

NOTE: When necessary, power source estimated as 25% of body weight

Non-Ragone Plot

If 25% of biological systems were "power source," some systems dramatically break the mold!

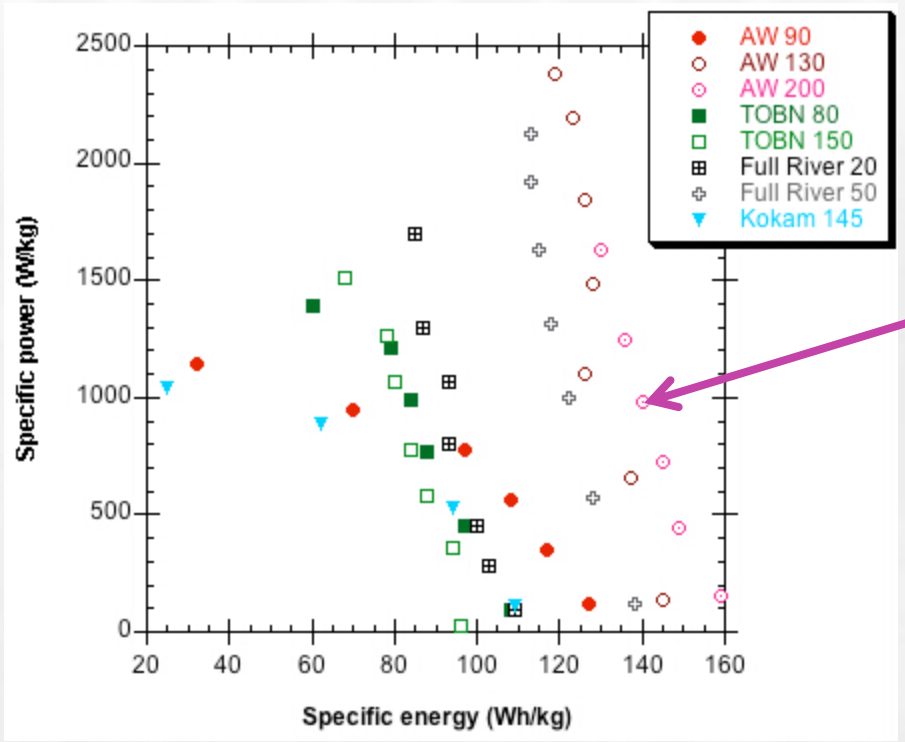


NOTE: When necessary, power source estimated as 25% of body weight

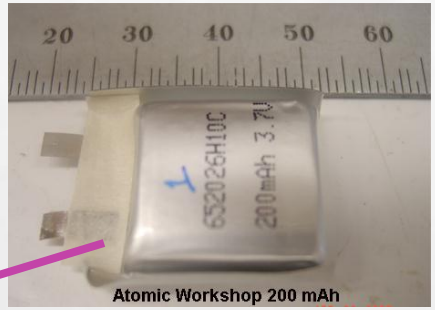
Option 1:

Bring what you need

COTS Rechargeables



*Stux & Swider-Lyons, NRL Report MR/6110-07-9073 , 2007

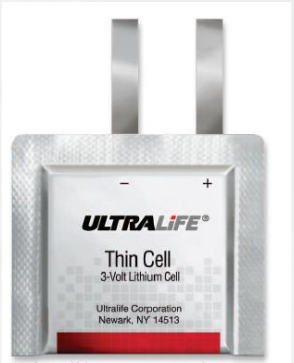


4.7g LiPo battery

- *Typically <$10*
- *Available down to ~1g*

COTS Primary Batteries

Plenty of energy (300-400 Whr/kg);
Power Density limited (typically <100 W/kg)



ultralifecorporation.com

U10004 – 15g
~300 Whr/kg; 25 W/kg

ultralifecorporation.com

UHE-ER14505 – 18g
~400 Whr/kg ; 17 W/kg

Specific Power of Source (W/g)

1

COTS Rechargeable Batteries (<150 Whr/kg)

Primary Batteries

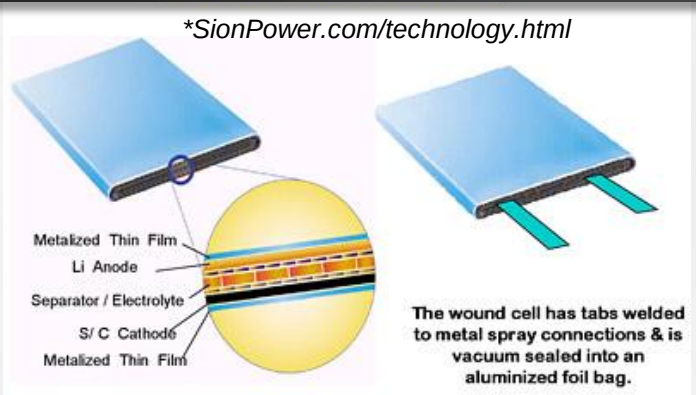
Endurance (Hours)

2

Emerging Batteries: Secondary used as a Primary

<u>Typical Li-S problem:</u> performance degrades with cycling
→ Commercial electronics care; MAST does not!

*SionPower.com/technology.html



16g, 2V battery

- *Lithium-Sulfur: promising rechargeable technology*
  - *→Up to 350 Wh/kg at 60 W/kg*
  - *→Project >200 Wh/kg @ 800 W/kg*

Specific Power of Source (W/g)

1

Battery Research

COTS Rechargeable Batteries (<150 Whr/kg)

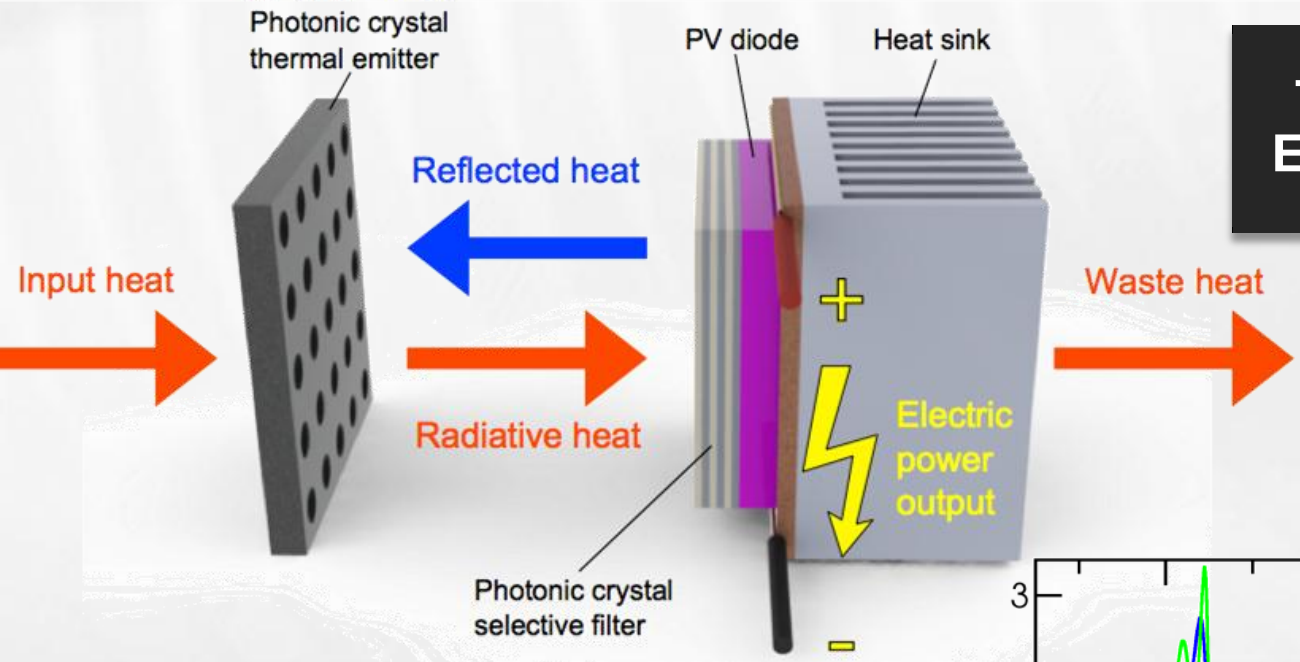
Primary Batteries

Endurance (Hours)

2

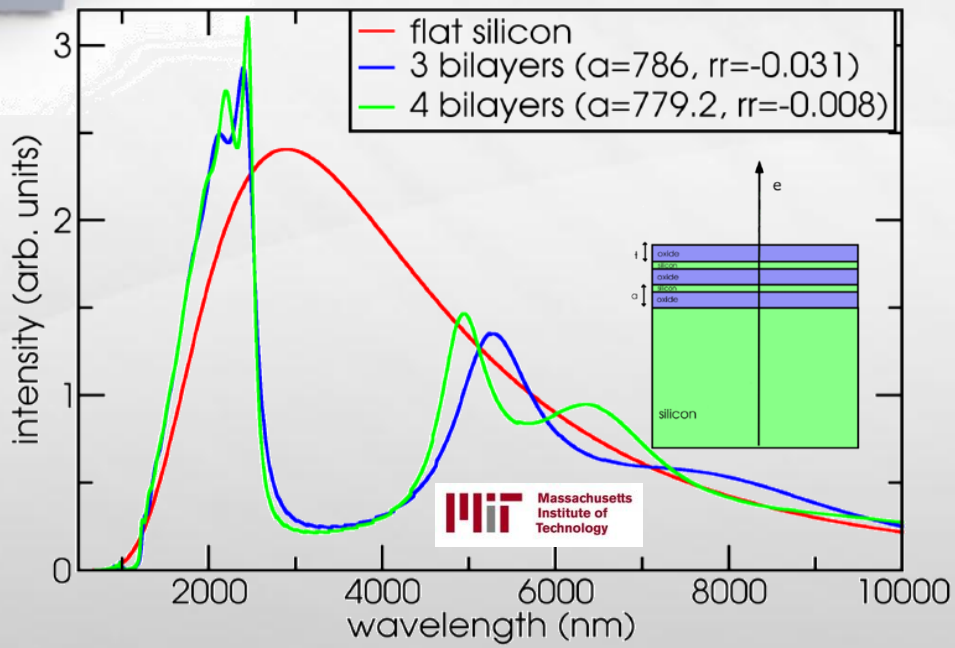
Thermo-Photovoltaics

ARL

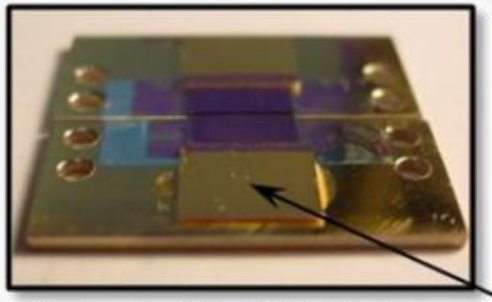


Thermal Radiation to Electricity via a PV cell

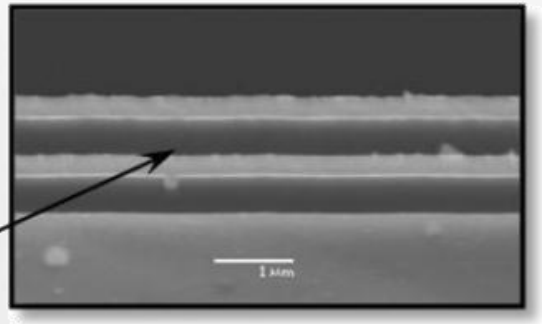
Photonic Crystals Predicted to Double System Efficiency



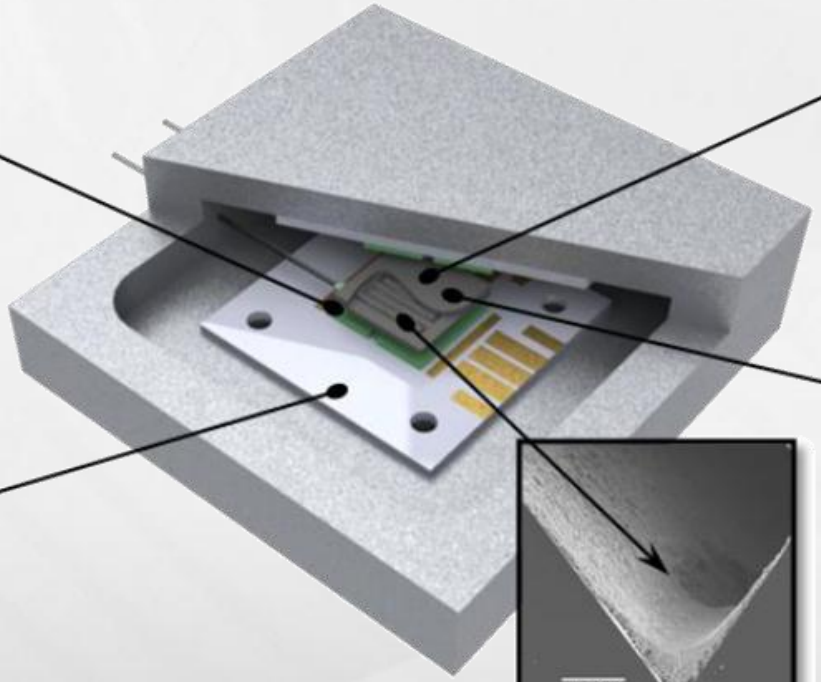
Micro-Thermo-Photovoltaics

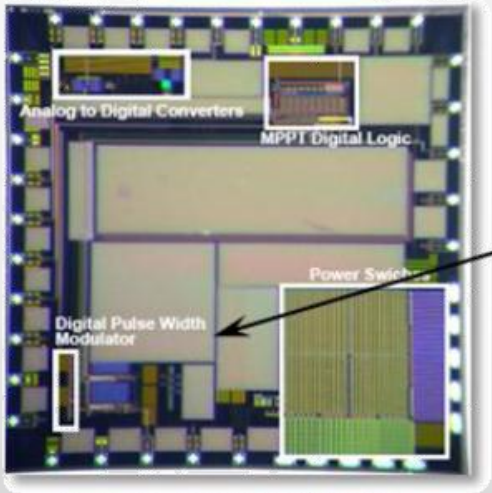


GaInAsSb PV diodes



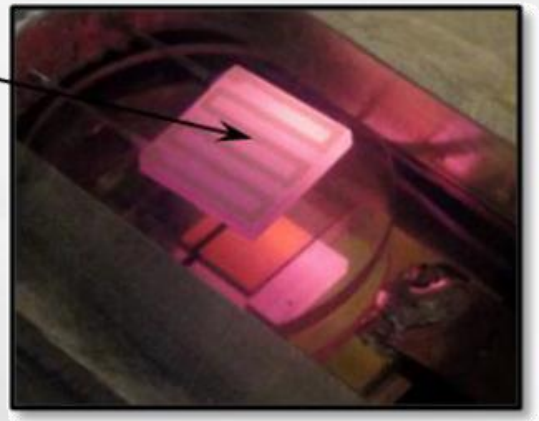
1D PhC emitter





low-power MPPT

micro channel

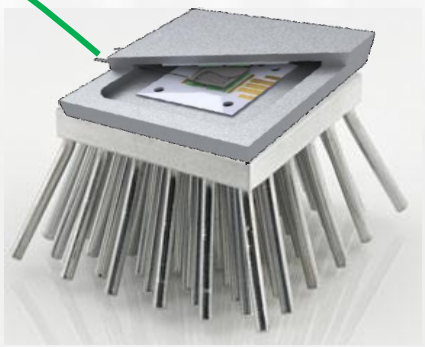


Silicon MEMs reactor

POC: Ivan Celanovic

Massachusetts Institute of Technology

Micro-Thermo-Photovoltaics



1st Order Calculations for a hypothetical <25g, 5W propane-fueled "system"

Component	Mass	Performance
Reactor & TPV Cells	5-8g	5-20%
Packaging	.5-1g	--
Heat sink	3-5g	--
Pumps , Power Elec	.5-1g	1W, 90%
Fuel to Tank Ratio	2:1 to 10:1	--

Battery

R

Micro TPV?

COTS Rechargeable Batteries (<150 Whr/kg)

Primary Batteries

Specific Power of Source (W/g)

1

Endurance (Hours)

2

Option 2:

Get more energy on site

Solar Photovoltaics

Ideal Outdoor Solar

1000 W/m²

~20% Efficient
~80% Fill Factor
~65 g/m²

>1 W/g

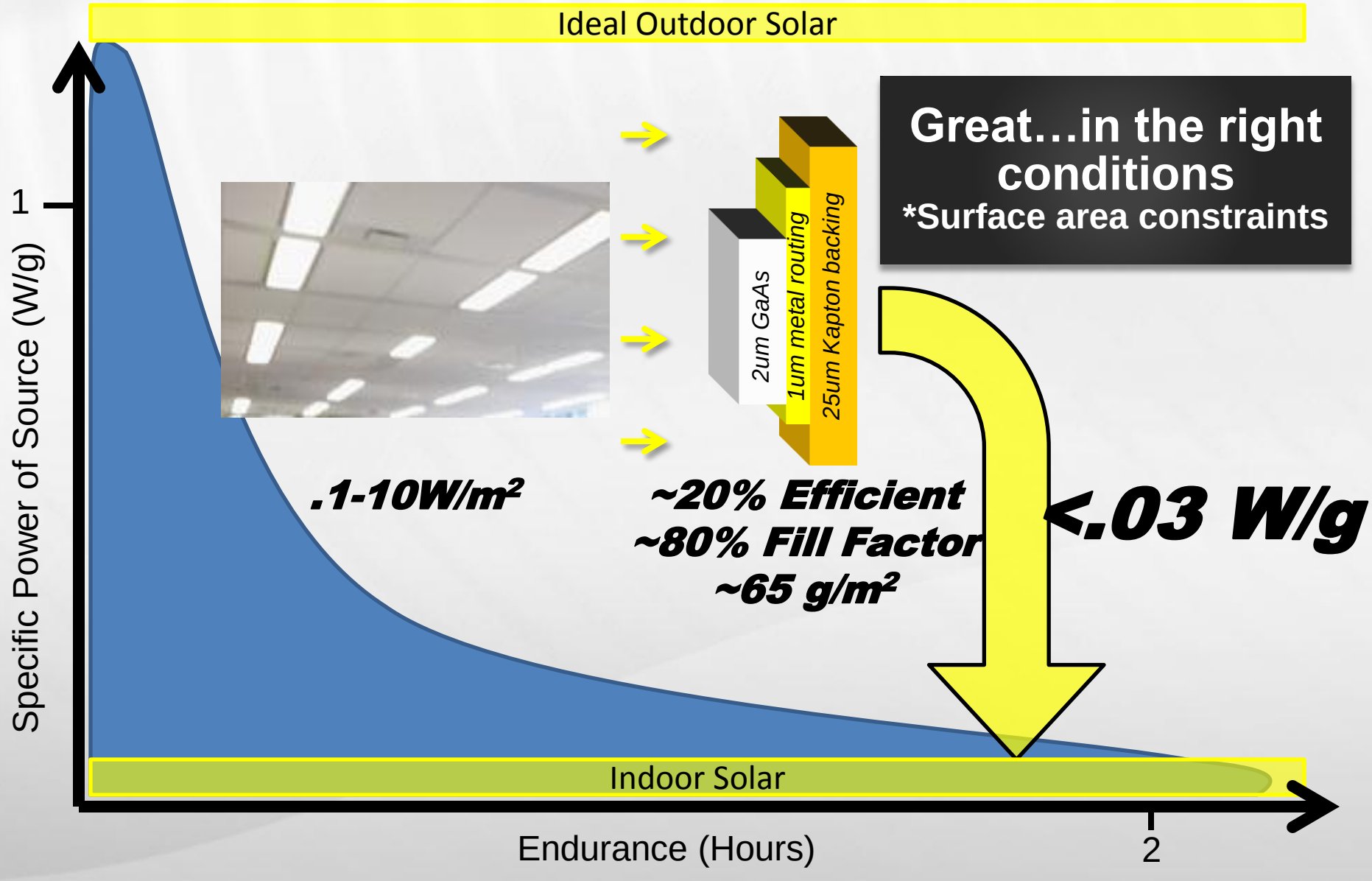
Specific Power of Source (W/g)

1

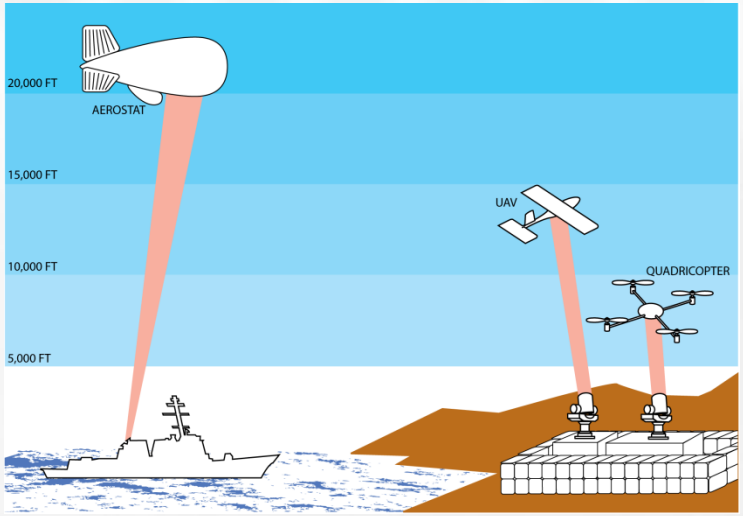
Endurance (Hours)

2

Solar Photovoltaics



Power Beaming



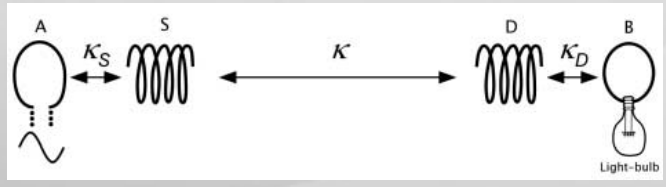
Pro's:*
>20% Net Efficiency
Scalable to kW & km
800 W/kg (receivers)

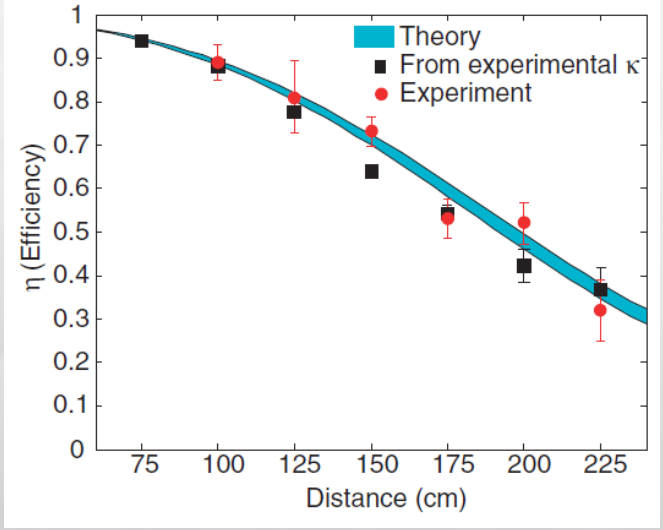
*Nugent & Kare, SPIE DSS, 2011

LaserMotive

Con's:
Line of sight
Safety & reflections

Demonstrated 60W over 2m at 40-50% efficiency (~60cm coils)

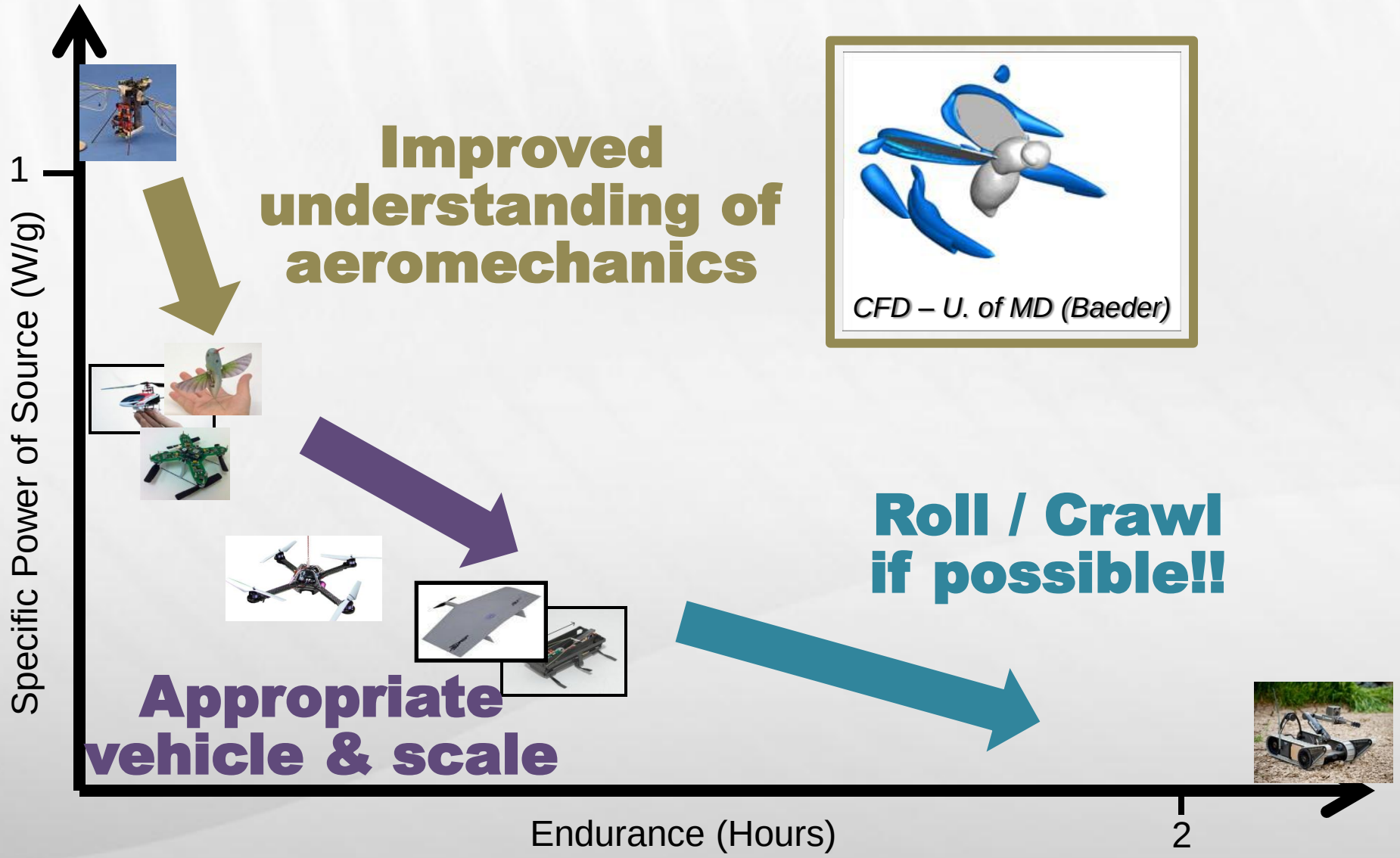




*Kurs et al, Science, 2007

Suggestions

Use Less Power



NOTE: When necessary, power source estimated as 25% of body weight

Match Needs to Use

Some Missions Do Not Need Continuous Flight

COTS

200g LiPo

Single 26min flight

vs.

Hybrid

150g Primary + 50g LiPo

8 flights
(6 min each,
30 min re-charges)

~2X*
Hybrid Battery

Assume:
LiPo = 150 Wh/kg @ 1.5 W/g
Primary = 350 Wh/kg @ 0.1 W/g

Specific Power of Source (W/g)

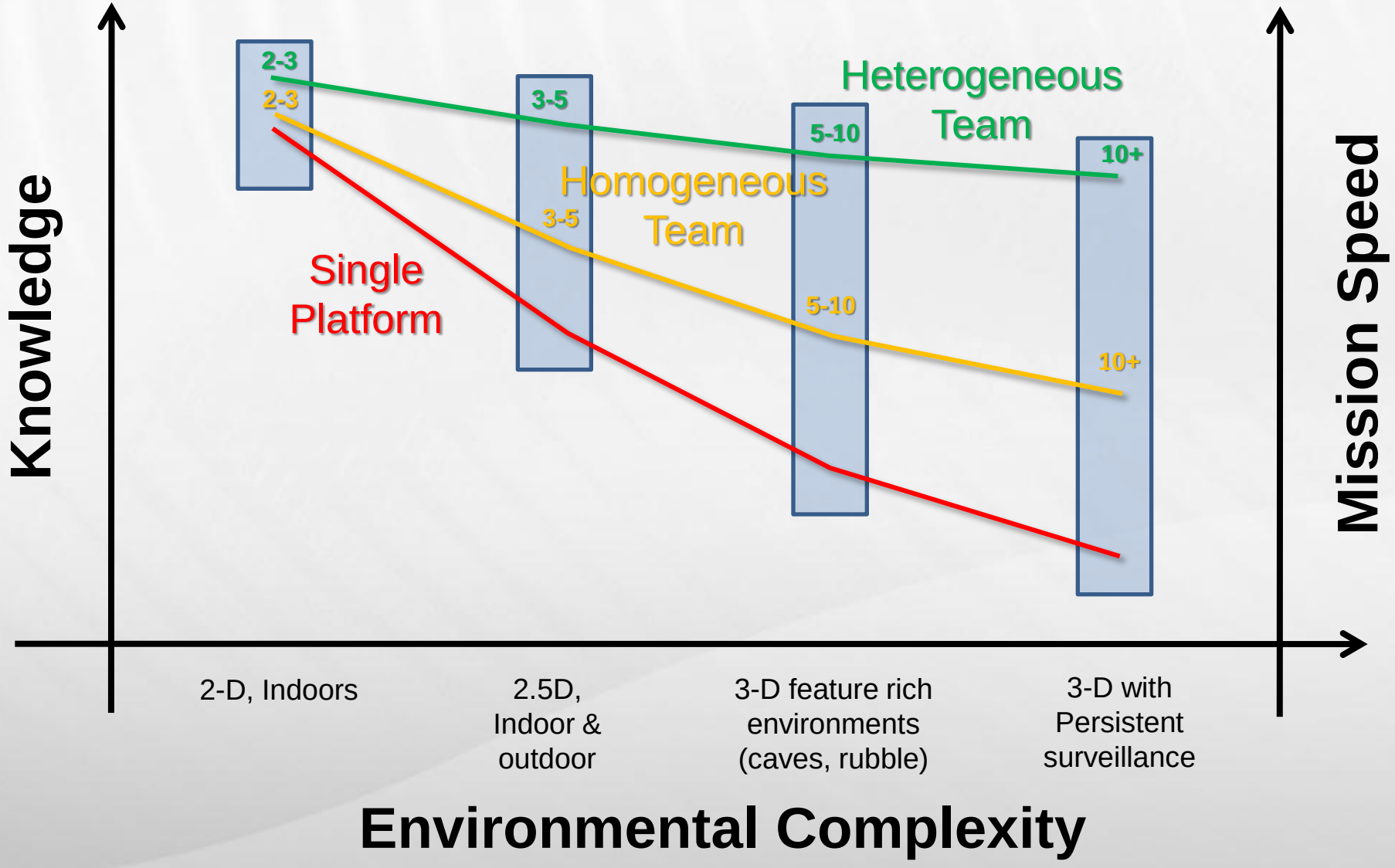
1

Primary Batteries

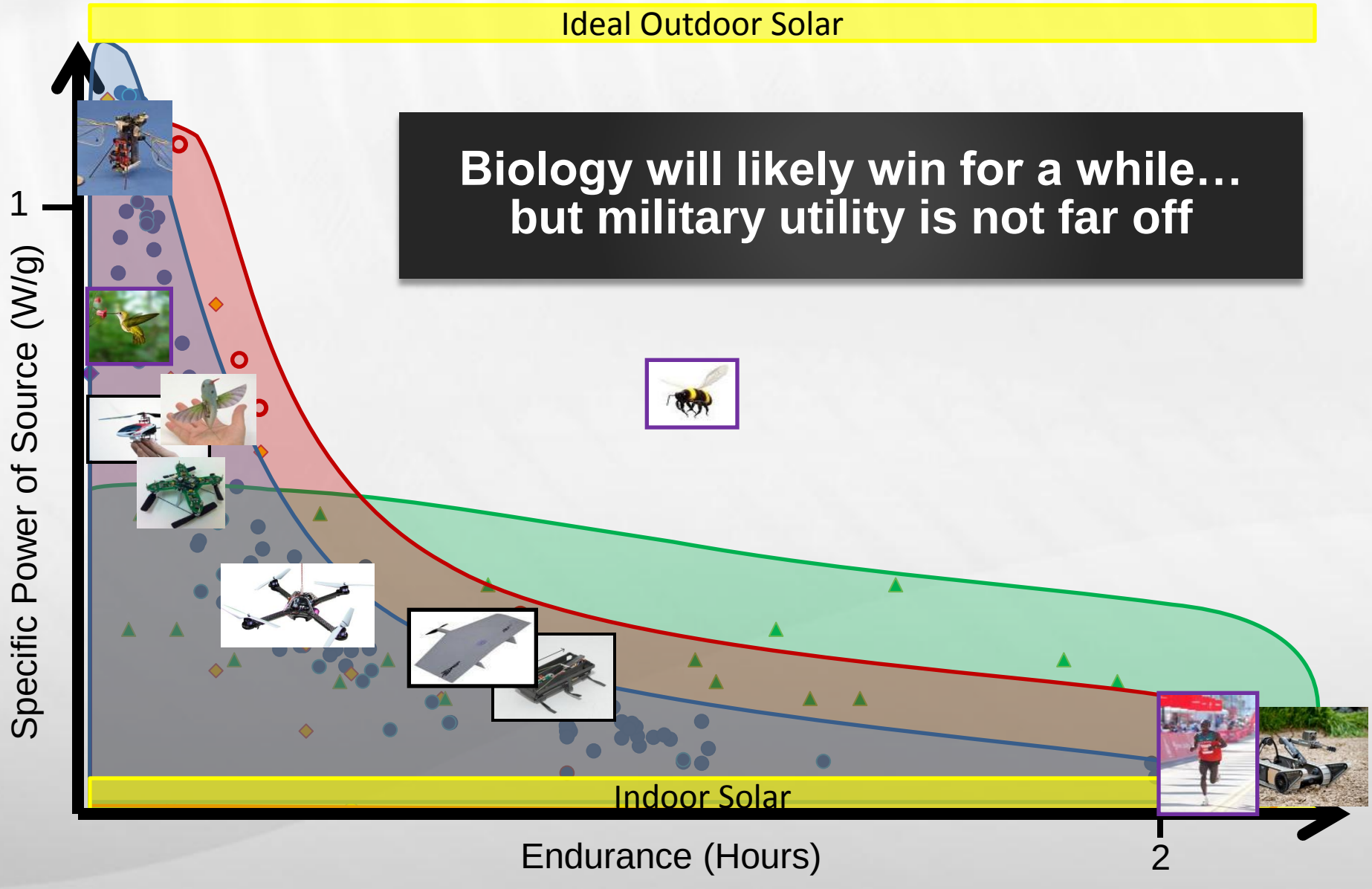
Endurance (Hours)

2

Embrace Cooperation



Final Non-Ragone Plot

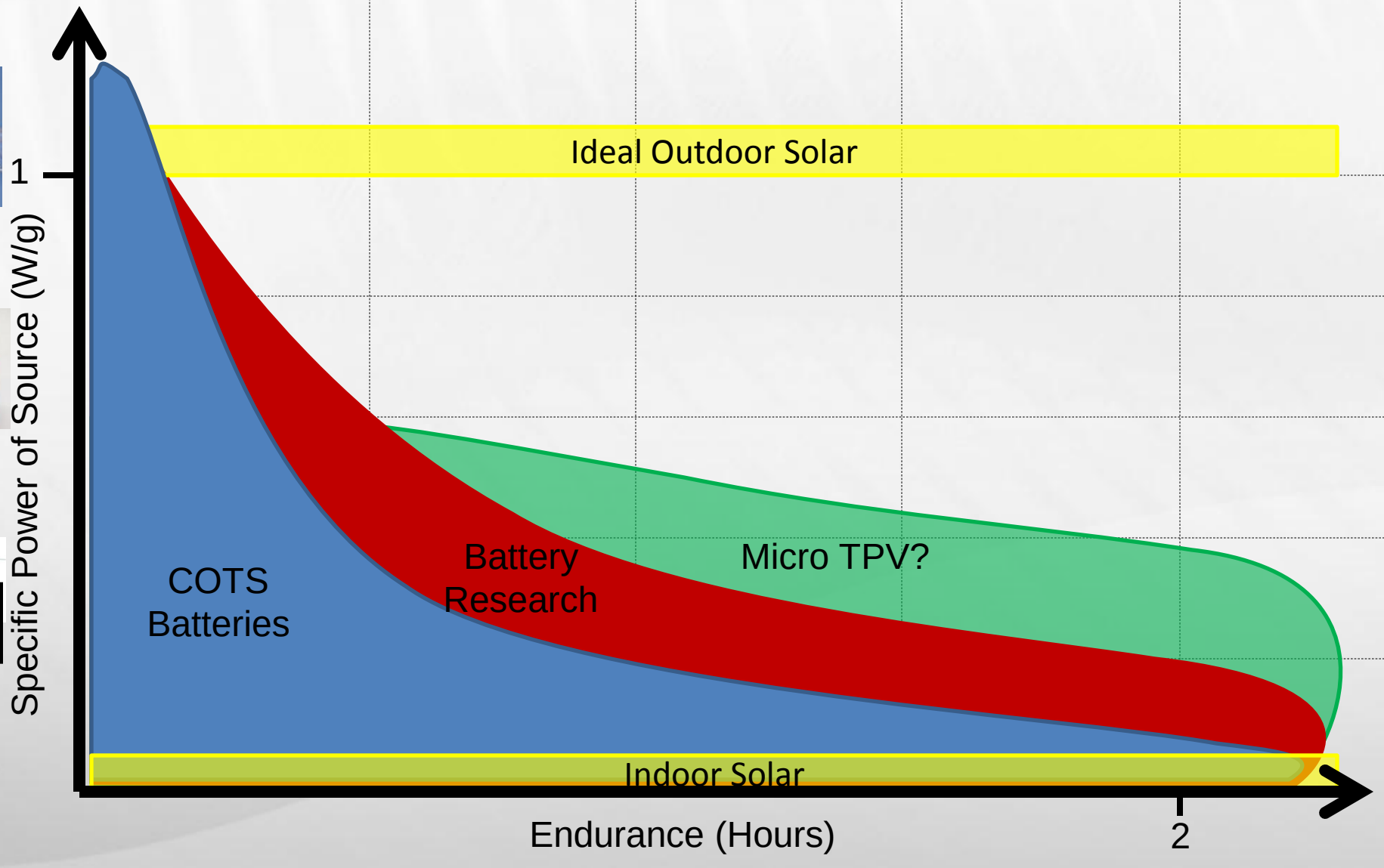


END

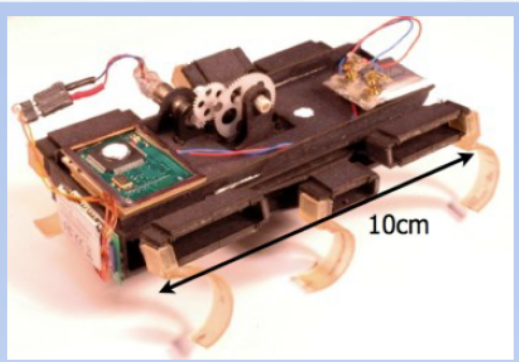
Non-Ragone Plot







Representative Platforms: DynaRoACH from UC Berkeley



Current dynaRoach 1.0 (24 grams)

- measured COT at cruise: 5 J/kg-m = 120 mW
- cruise speed: 1 m/sec (flat ground)
- total power for cruise: 600 mW
- range: 1.8 km
- max power density 10 W/kg (900 mW, 1000 sec) (Hoover et al BioRob 2010)v

motor 3 grams 0.24/0.6 W	LiPo 2.5 grams 1100 J	Structure 17 grams	CPU 1.5 grams 0.3 W

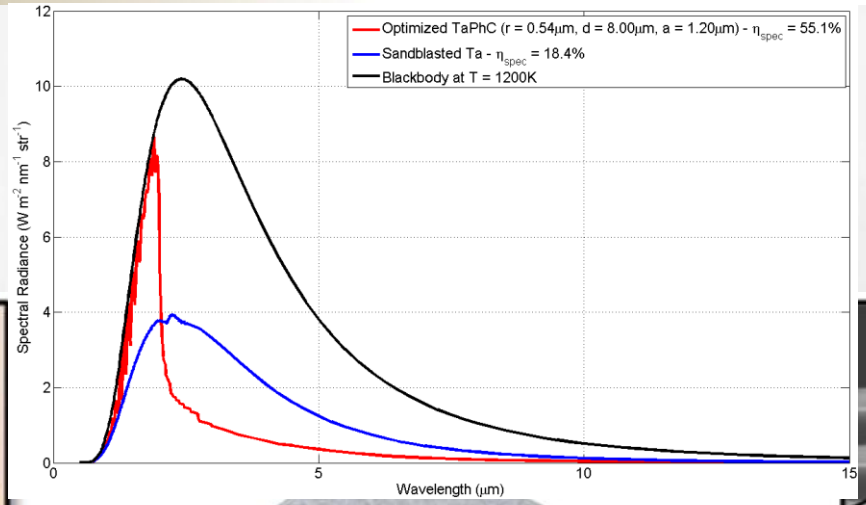
motor 1.7 grams 0.6/1.5 watts	LiPo Battery 3.2 grams 1600 J	proposed structure Goal: 3.6 grams	CPU 1.5 grams 50 mW

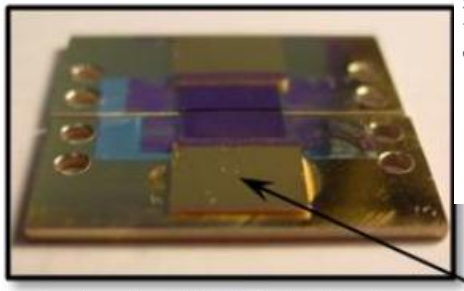
Hypothetical dynaRoach 2.0 (10 grams)

- COT at cruise: 2 J/kg-m = 40 mW
- cruise speed: 2 m/sec (flat ground)
- total power for cruise: 130 mW
- range: 25 km
- max power density 150 W/kg (3000 mW, 500 sec)

**Ron Fearing, "Power & Energy for Small Robotic Systems," 2010 Army Science Conference*

Micro-Thermo-Photovoltaics





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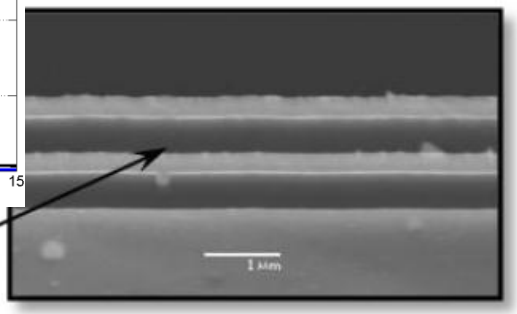

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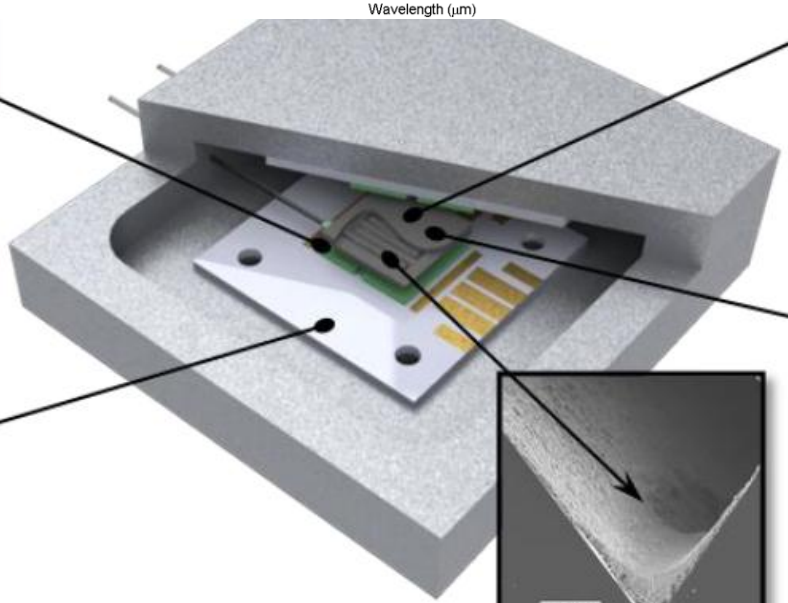
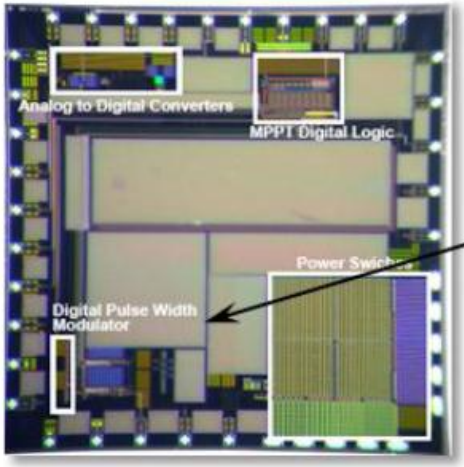
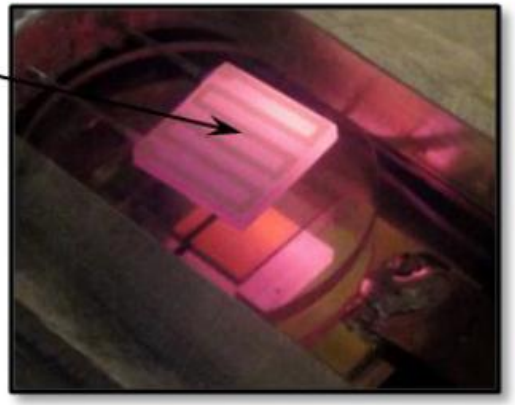




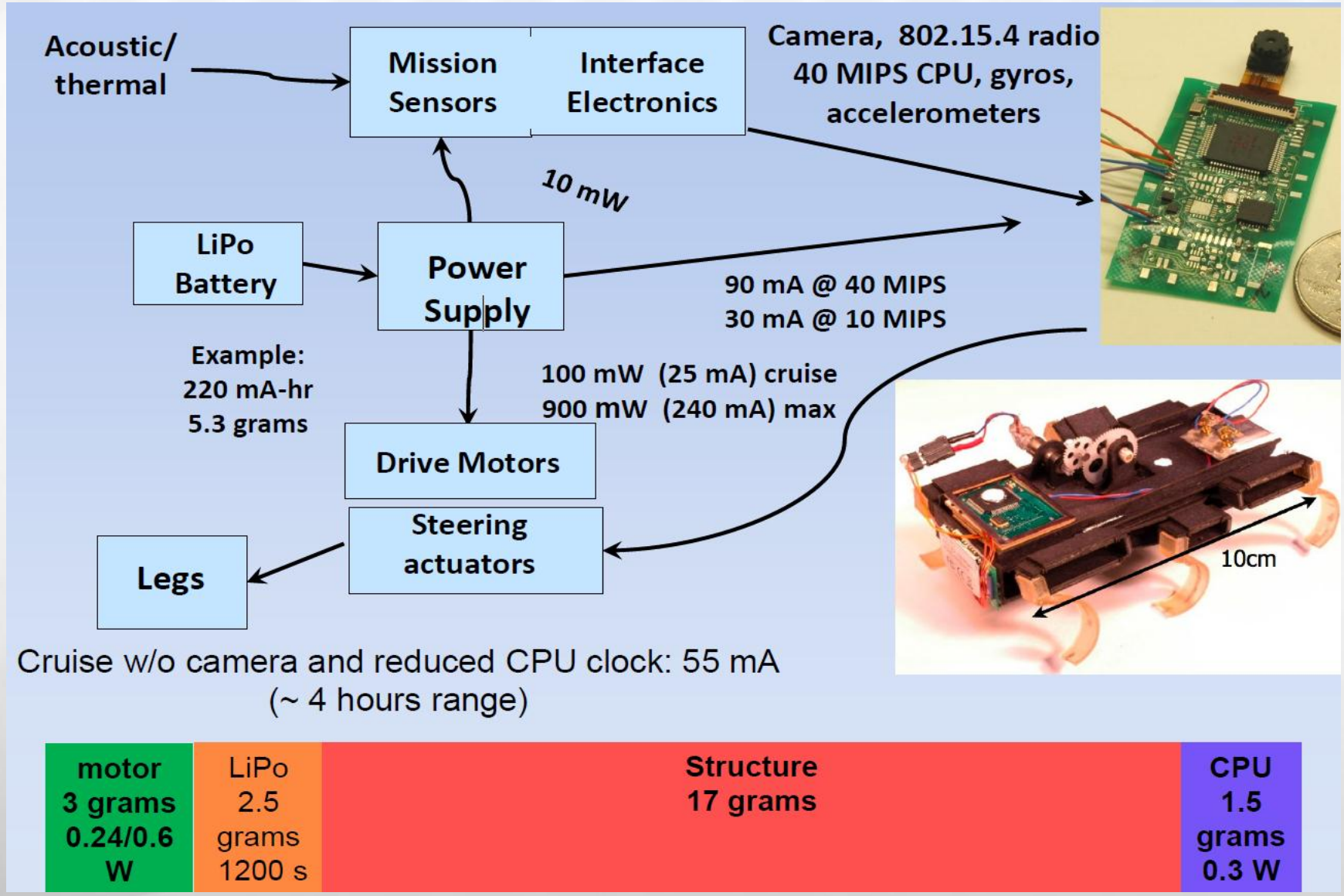
low-power MPPT

micro channel

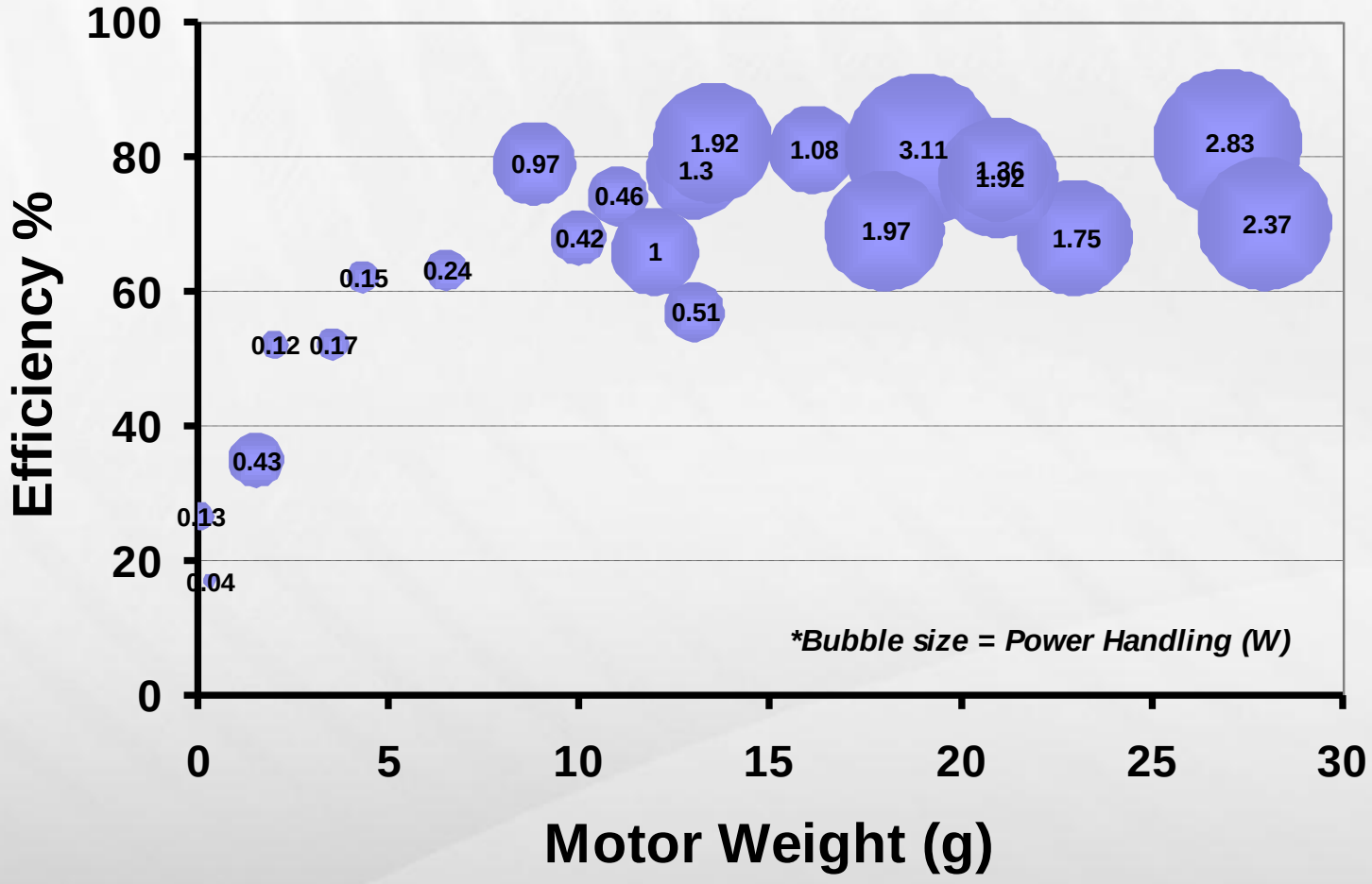


Silicon MEMs reactor

Representative Platforms: DynaRoACH from UC Berkeley



*Ron Fearing, "Power & Energy for Small Robotic Systems," 2010 Army Science Conference


Efficiency %
100
80
60
40
20
0
0
5
10
15
20
25
30
Motor Weight (g)
0.97
1.92
1.3
1.08
3.11
1.36
1.92
2.83
0.46
0.42
1
1.97
1.75
2.37
0.15
0.24
0.51
0.12
0.17
0.43
0.13
0.04
*Bubble size = Power Handling (W)